ORIGINAL ARTICLE

Liver Sharing and Organ Procurement Organization Performance

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Whether the liver allocation system shifts organs from better performing organ procurement organizations (OPOs) to poorer performing OPOs has been debated for many years. Models of OPO performance from the Scientific Registry of Transplant Recipients make it possible to study this question in a data-driven manner. We investigated whether each OPO's net liver import was correlated with 2 performance metrics [observed to expected (O:E) liver yield and liver donor conversion ratio] as well as 2 alternative explanations [eligible deaths and incident listings above a Model for End-Stage Liver Disease (MELD) score of 15]. We found no evidence to support the hypothesis that the allocation system transfers livers from better performing OPOs to centers with poorer performing OPOs. Also, having fewer eligible deaths was not associated with a net import. However, having more incident listings was strongly correlated with the net import, both before and after Share 35. Most importantly, the magnitude of the variation in OPO performance was much lower than the variation in demand: although the poorest performing OPOs differed from the best ones by less than 2-fold in the O:E liver yield, incident listings above a MELD score of 15 varied nearly 14-fold. Although it is imperative that all OPOs achieve the best possible results, the flow of livers is not explained by OPO performance metrics, and instead, it appears to be strongly related to differences in demand. *Liver Transpl 21:293-299, 2015*. © **2015 AASLD.**

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Livers from deceased donors in the United States are most frequently allocated at the local level to candidates in the same organ procurement organization (OPO) where the liver was recovered. A liver recovered in one OPO and transplanted at a center in a different OPO is said to have been exported from the source OPO and imported to the destination OPO. Although OPOs endeavor to increase consent rates for donation[1] and to provide optimal medical management for donors,[2] some are still net importers, and some are net exporters; the mechanism for this remains unclear.

The flow of livers among OPOs is of great concern to many in the transplant community, and some have hypothesized that the liver allocation system funnels livers from better performing OPOs to poorer performing OPOs; this concern has been particularly great since the Share 35 modification to liver allocation.

Abbreviations: MELD, Model for End-Stage Liver Disease; O:E, observed to expected; OPO, organ procurement organization; OPTN, Organ Procurement and Transplantation Network; SRTR, Scientific Registry of Transplant Recipients.

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Preferentially exporting livers from better performing OPOs to poorer performing OPOs might conceivably undermine the incentives that transplant centers have to work with their local OPOs to raise local donation rates and improve OPO practices. On the other hand, a nationally representative survey recently concluded that only 10% of Americans oppose regional sharing of deceased donor organs,[3] so suggestions that the flow of organs among OPOs will discourage people from donating their organs seem unfounded.

An OPO performance metric is a measure of the OPO's success at obtaining organs for transplantation. Designing meaningful OPO performance metrics is not trivial; for example, the number of donors per million population is not a good metric because demographics, death rates, and causes of death vary greatly across the country.[4] The Scientific Registry of Transplant Recipients (SRTR) now publishes periodic OPO performance evaluations that include 2 important measures: (1) the observed to expected (O:E) liver yield ratio and (2) the liver donor conversion ratio.[5] These metrics provide an opportunity to study the relationship between OPO liver flow and OPO performance, but this relationship has not yet been explored.

To better understand OPO liver flow in the United States and to determine if the hypothesized side effect of the liver allocation system is occurring, we studied the correlation between each OPO's net import and the 2 SRTR OPO performance evaluations (O:E liver yield and liver donor conversion ratio). In exploring alternative hypotheses, we also studied correlations with O:E incident liver listings above a Model for End-Stage Liver Disease (MELD) score of 15 and O:E eligible deaths. Finally, given the recent change in the organ allocation policy,[6] we studied these correlations both before and after Share 35.

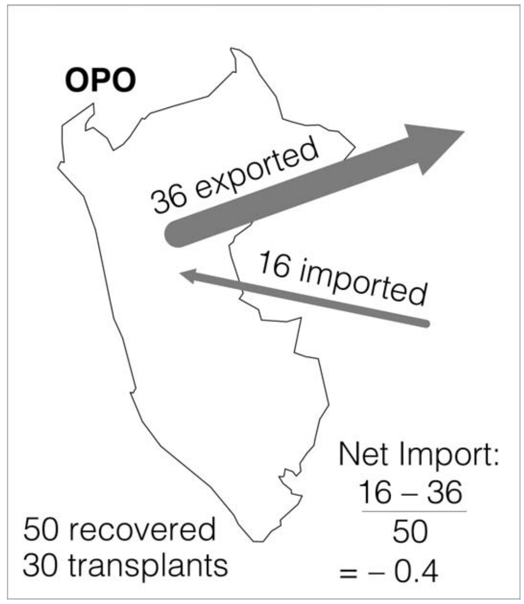

Figure 1. Illustration of the net import calculation. Net import is defined as the difference between imported livers and exported livers divided by the livers recovered by the OPO: (import − export) ÷ recovered. Net import could range from −1 (recovers livers and exports all of them) to $+\infty$ (recovers no livers and transplants only imports).

PATIENTS AND METHODS

Study Population

Adult (≥18 years of age) deceased donor liver transplants from 2010 to 2011 (n = 11,659), eligible deaths from 2010 (n = 8982), incident listings for adult liver transplantation from 2010 to 2011 (n = 11,159), and 2010 adult population ratios from the US Census Bureau were used in the primary analysis. As a sensitivity analysis to test whether our findings were consistent since the implementation of Share 35, we studied adult deceased donor liver transplants from June 18, 2013 to April 4, 2014 (n = 4369), eligible deaths from 2010 (n = 8982), and incident listings for adult liver transplantation from June 18, 2013 to April 4, 2014 (n = 4513).

This study used data from the SRTR. The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the United States and is submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration of the US Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors.

Net Import

Net import was used to measure the direction and magnitude of liver flow into or out of an OPO. Organs recovered in an OPO other than the recipient's OPO were considered imports to the recipient OPO, and exports were from the donor OPO (Fig. 1). We defined an OPO's net import as the difference between imports and exports. When the net import was 0, the OPO imported as many livers as it exported. When the net import was positive, the OPO imported more livers than it exported.

We divided by the number of organs recovered to normalize for differences in OPO volumes. The raw count of imports or exports reflected the size of the OPO, whereas the normalized net import captured whether an OPO was importing or exporting a significant proportion of its local organ supply. For example, Hawaii's OPO exported 33% of recovered organs (net import = –0.33), which was 5 livers exported of 15 recovered; Michigan's OPO exported less than 4% of recovered organs (net import = –0.039), which was 5 livers exported of 129 recovered.

Potential Correlates

The 2 measures of OPO performance that were used by the SRTR were considered in this analysis: (1) the liver donor conversion ratio and (2) the O:E liver yield. The other potential correlates, O:E incident listings and O:E eligible deaths, were novel measures designed in the context of this study to reflect disparities and donor and candidate counts per OPO. We studied the range of variation of each potential correlate among OPOs.

Liver Donor Conversion Ratio

The liver donor conversion ratio was calculated, as defined by the SRTR, as the proportion of eligible deaths that are converted into liver donors in an OPO. A deceased individual was considered an eligible death if he or she met certain criteria for age, neurologic death, and other exclusions of infection or malignancy.[5] The liver donor conversion ratio was, as such, the unadjusted observed liver-specific donation rate (which can be found in Table C2 of the SRTR OPO-specific reports)[9] divided by 100. For example, if every eligible death in an OPO resulted in a recovered liver, the liver donor conversion ratio would be 1.0; if only half of the eligible deaths resulted in liver donations, then the ratio would be 0.5. A better performing OPO would have a liver donor conversion ratio nearer to 1, which would indicate that a high proportion of its eligible deaths led to liver donation. The liver donor conversion ratio from 2010 to 2011 was used for the primary analysis. The liver donor conversion ratio from 2012 to 2013 was used for the Share 35 sensitivity analysis.

O:E Liver Yield

The observed liver yield was calculated, as defined by the SRTR, as the actual number of liver donations per 100 donors reported to the SRTR for a given time frame and OPO. The expected liver yield, also as defined by the SRTR, was calculated as a predicted number of liver donations per 100 donors on the basis of an adjusted linear regression model.[5] The O:E liver yield was, as such, the O:E ratio for livers, which can be found in Table C3 of the SRTR OPO-specific reports.[9] A better performing OPO would be one with an O:E ratio higher than 1, that is, an OPO that generated more liver transplants from its donors than expected. Similarly, a poorer performing OPO would be one with an O:E ratio lower than 1. The O:E liver yield from 2010 to 2011 was used in the primary analysis, and the O:E liver yield from 2012 to 2013 was used in the Share 35 era sensitivity analysis.

O:E Eligible Deaths

O:E eligible deaths were defined for the purposes of this study as follows: (eligible deaths in OPO/national eligible deaths) ÷ (population in OPO/national population). This metric was designed to measure the prevalence of eligible deaths in each OPO normalized to the OPO's population with respect to the national population. Because the reporting of eligible deaths is lagged, both the primary analysis and the Share 35 sensitivity analyses used eligible deaths from 2010 to 2011.

O:E Incident Listings

O:E incident listings were defined for the purposes of this study as follows: (listings in OPO/national listings) ÷ (population in OPO/national population). They included all observed incident listings for liver transplantation in the United States with a laboratory MELD score greater than 15 at the time of listing. This metric was designed to measure how many new registrants were waiting for deceased donor livers in each OPO with normalization to the OPO's population with respect to the national population. The primary analysis used incident adult liver-only listings from 2010 to 2011, whereas the Share 35 era sensitivity analysis used incident adult liver-only listings from June 18, 2013 to April 4, 2014.

Association Between Net Import and Potential Correlates

The net import ratios were calculated for the 50 OPOs that serve local liver transplant programs. A linear model of the net import and each of the potential correlates was fitted, with weighting by the number of organs recovered in each OPO. The significance of each of the potential correlates in a linear fit and the correlation coefficients are reported. These correlations were calculated for 2010 to 2011 in the primary analysis and separately for the Share 35 sensitivity analysis.

RESULTS

Net Importing and Net Exporting OPOs

In the primary analysis, before Share 35, there were 27 OPOs that were net importers of livers and 31 OPOs that were net exporters of livers, of which 8 OPOs were not serving a liver transplant program. After Share 35, there were 25 OPOs that were net importers of livers and 33 OPOs that were net exporters of livers, of which 6 OPOs were not serving a liver transplant program. There were 2 OPOs that did not serve a liver transplant program during 2010 to 2011 but for which a liver transplant program had opened by the Share 35 era.

Net Import Versus OPO Performance Metrics

Twenty-eight OPOs (that served at least 1 liver transplant center) had an O:E liver yield ≥ 1 (this meant that they recovered more livers than expected given their case mix), whereas 22 OPOs had an O:E liver yield < 1 and recovered fewer than expected. Of OPOs with an O:E liver yield ≥ 1, 61% were net importers, and 39% were net exporters; of 22 OPOs with an O:E liver yield < 1, 45% were net importers, and 55% were net exporters. There was no association between being a net importer/exporter and having a higher/lower

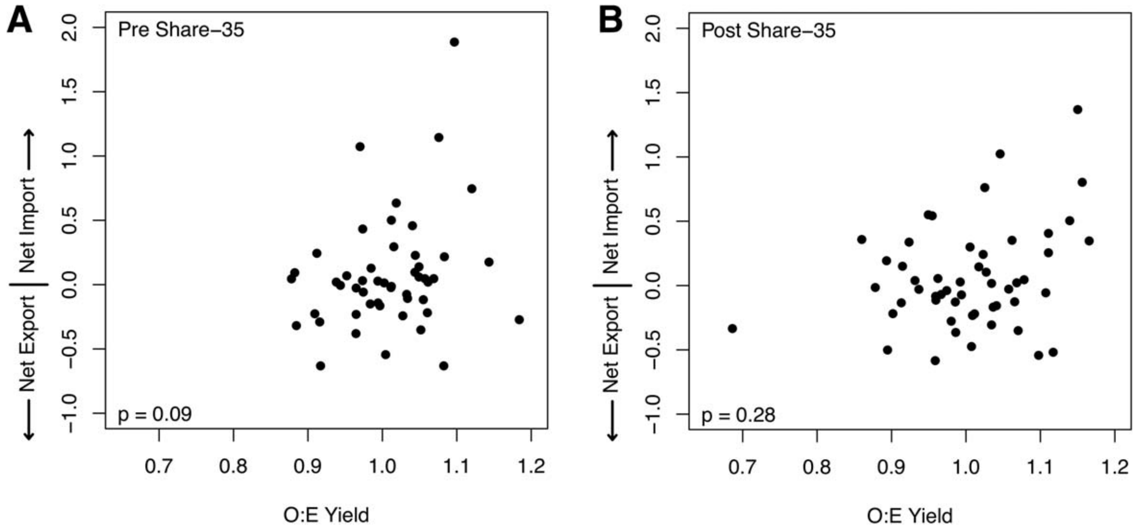

Figure 2. Net import versus O:E liver yield, with pre-Share data in panel A and post-Share data in panel B. The outlier point in the post–Share 35 O:E yield is HIOP (Hawaii), with an O:E yield of 0.69 and 15 recovered organs.

than expected liver yield, either before ($P = 0.28$) or after ($P = 0.16$) Share 35 (by a chi-square test). OPOs in the best performing quartile were primarily net importers, with a median net import of 0.05, whereas OPOs in the poorest performing quartile were primarily net exporters, with a median net import of –0.03. When we compared the O:E liver yield with the net import as continuous metrics, there was also no discernable relationship (Fig. 2; $P = 0.1$ before Share 35 and $P = 0.3$ after Share 35; P was calculated from a linear regression model). That is, livers did not flow from OPOs with a higher liver yield to OPOs with a lower liver yield, and if anything, they might have flowed from poorer performing OPOs to better performing OPOs.

Of OPOs with a higher than median liver donor conversion ratio, 48% were net importers, and 52% were net exporters; of OPOs with a liver donor conversion ratio lower than the median, 60% were net importers, and 40% were net exporters. There was no association between being a net importer/exporter and having a higher/lower than expected liver donor conversion ratio, either before ($P = 0.39$) or after ($P = 0.78$) Share 35 (by a chi-square test). The best performing quartile of OPOs was primarily composed of net exporters with a median net export of –0.03; the poorest performing quartile of OPOs was primarily composed of net importers with a median net import of 0.1. When we compared the liver donor conversion ratio with the net import as continuous metrics, there was also no discernable relationship (Fig. 3; $P = 0.09$ before Share 35 and $P = 0.09$ after Share 35; P was calculated from a linear regression model). That is, livers did not flow from OPOs with a higher liver donor conversion ratio

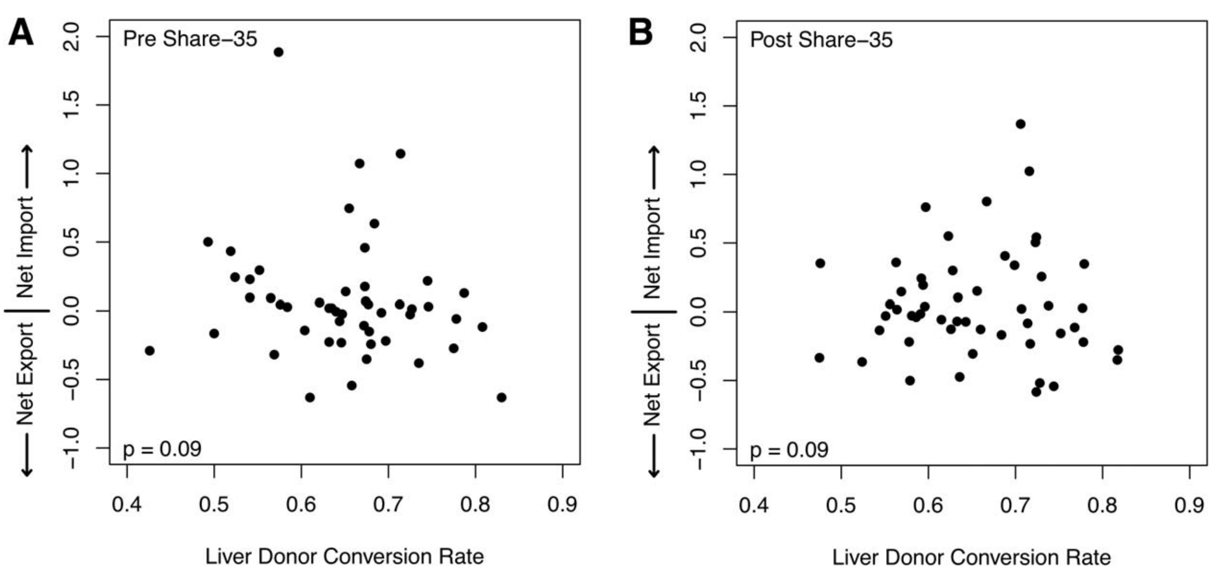

Figure 3. Net import versus the liver donor conversion ratio, with pre-Share 35 data in panel A and post-Share 35 data in panel B.

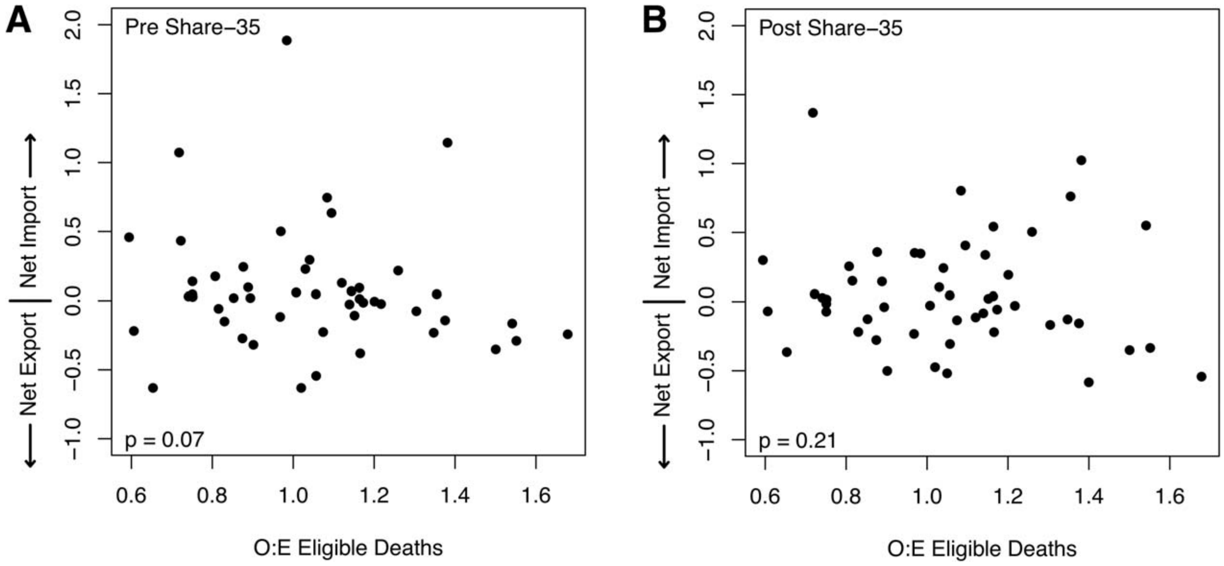

Figure 4. Net import versus O:E eligible deaths, with pre-Share 35 data in panel A and post-Share 35 data in panel B.

to OPOs with a lower liver donor conversion ratio, and if anything, they might have flowed from poorer performing OPOs to better performing OPOs.

Net Import Versus Supply and Demand

There was no statistically significant association between the net import and the eligible deaths, either in the primary analysis or after Share 35 ($P = 0.06$ and $P = 0.18$, respectively). That is, livers did not flow from OPOs with higher eligible death rates to those with lower eligible death rates. Figure 4 shows no discernable relationship between eligible deaths and net import; for example, the 5 highest importing OPOs ranged from the highest to lowest values for O:E eligible deaths.

However, there was a strong, statistically significant association between net import and incident listings in both the primary analysis and the analysis after Share 35 ($P < 0.001$). The correlation was positive, with a correlation of 0.75 in the primary analysis and a correlation of 0.72 after Share 35 (Fig. 5). That is, livers flowed from OPOs with lower incident listings to OPOs with higher incident listings. Figure 5 shows a strong relationship between incident listings and net import, with all 10 of the highest

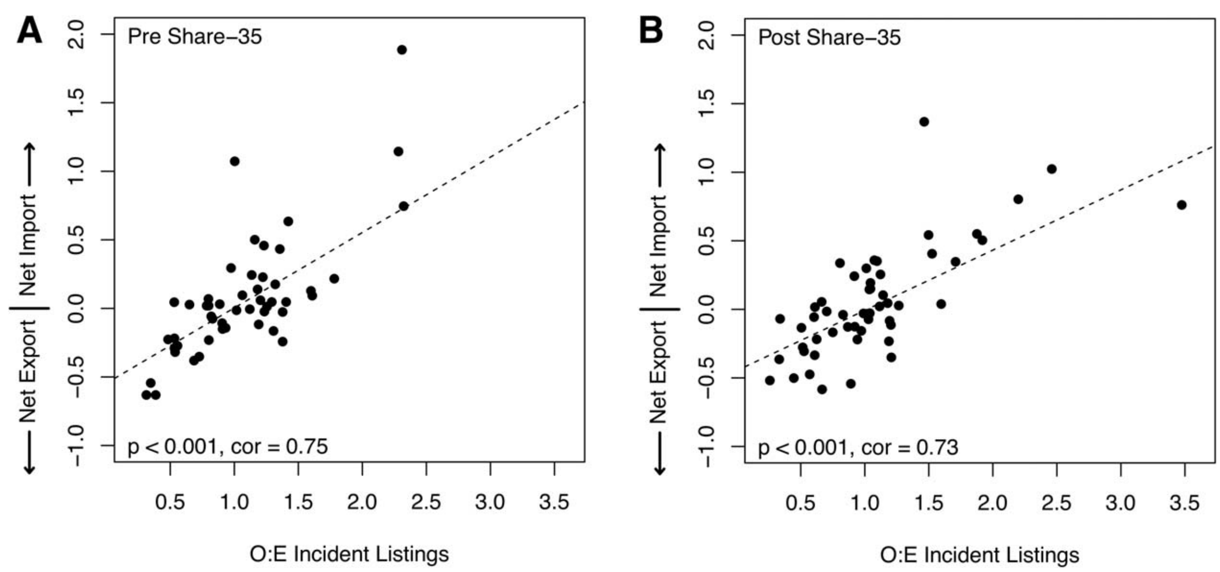

Figure 5. Net import versus O:E incident listings, with pre-Share 35 data in panel A and post-Share 35 data in panel B. Before Share 35, the regression equation was net import = –0.537 + 0.544 × OE incident listings ($P < 0.001$ for the intercept and slope) with an adjusted R^2 value of 0.4474. After Share 35, the regression equation was net import = –0.445 + 0.437 × OE incident listings ($P < 0.001$ for the intercept and slope) with an adjusted R^2 value of 0.4465.

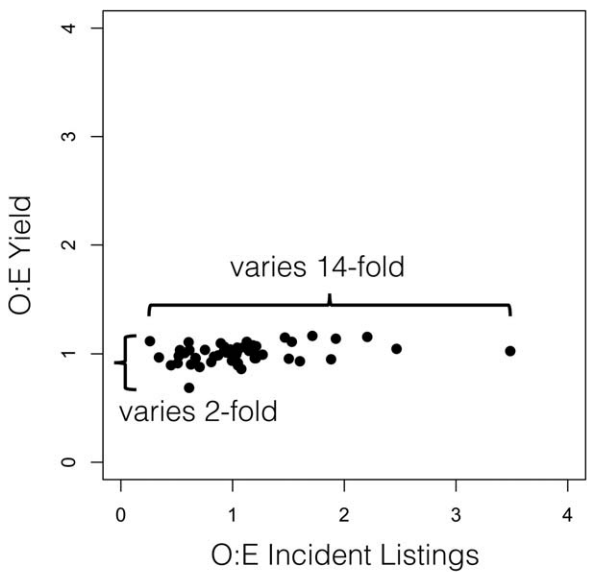

Figure 6. Differences in the range of O:E liver yields and the range of O:E incident listings for different OPOs in the Share 35 era.

importing OPOs having more incident listings than expected and with all 5 of the lowest importing OPOs having fewer incident listings than expected. In the primary analysis, the regression equation was net import = $-0.537 + 0.544 \times$ O:E incident listings ($P < 0.001$ for intercept and slope), so each unit increase in the O:E incident listings was associated with a 0.544 increase in the net import.

Range of Variation of Potential Correlates Across OPOs

After Share 35, the O:E liver yield varied by a factor of less than 2, from the worst-performing OPO with an O:E liver yield of 0.69 to the best performing OPO with an O:E liver yield of 1.17. Similarly, the liver donor conversion ratio varied by a factor of approximately 2, from the worst-performing OPO with a ratio of 0.433 to the best performing with a ratio of 0.818, and O:E eligible deaths varied by a factor of approximately 3, with a range of 0.54 to 1.69. Conversely, the O:E incident listings varied by a factor of almost 14 and ranged from 0.26 to 3.49. In other words, incident listings varied much more between OPOs than OPO performance measures did (Fig. 6).

DISCUSSION

We found no evidence to support the assertion that the liver allocation system transfers livers from better performing OPOs to poorer performing OPOs. We examined 2 very different OPO performance metrics, an adjusted ratio of the O:E liver yield and an unadjusted measure of liver donation probability among eligible deaths (liver donor conversion ratio), and we reached the same conclusion in both cases. The net import of livers was not associated with either OPO performance metric, either before or after Share 35. The only association we tested that reached statistical significance was that livers were transferred from OPOs where there were fewer incident listings at MELD scores ≥ 15 to centers in OPOs where there were more incident listings at MELD scores ≥ 15.

Our findings are consistent with those of Yeh et al.,[7] who studied geographic disparities as reflected by the allocation MELD scores at transplantation. In their study, they found that new listings per million population were associated with Donor Service Area (DSA) quartiles of increasing MELD scores at transplantation (ranging from 16.9 to 27.9, $P = 0.008$), but eligible deaths recovered per million, liver donors per million, and donor conversion ratios were all statistically indistinguishable across DSA quartiles of MELD scores at transplant. Rather than studying the MELD score at transplantation, we studied the net flow of livers (ie, importer/exporter OPOs), but our results were similar; we found an association with new listings, but not with the other metrics that we examined. This suggests that transplant centers wishing to increase transplant volumes might achieve that by listing more candidates.

The range of OPO performance in our study was narrow in comparison with the much wider range of incident liver transplant listings. In other words, although there are differences in OPO performance across the country, these are dwarfed by the magnitude of differences in incident transplant listings across the country. Therefore, in seeking an explanation for geographic disparities in liver transplantation, to focus solely on the variation in OPO performance would be misguided when the demand for liver transplantation varies over a 7-fold greater range. Different OPOs serve very different populations, but efforts such as the organ donor breakthrough collaborative should continue to focus on improving every OPO's performance by sharing best practices.[8]

Our inferences are limited by the metrics available to study. All OPO performance metrics have methodological limitations, including the ones that we examined here.[4] Eligible deaths are self-reported by the OPOs, so there may be variability among OPOs in capturing these. Many livers come from older or donation after cardiac death donors who are excluded from the calculation of the liver donor conversion ratio because these are not classified as eligible deaths. However, the OPO metrics that we used here are the ones that were chosen by the United Network for Organ Sharing, OPTN, SRTR, and SRTR Technical Advisory Committee; they are the best metrics currently available, and they do show variation across the country, but this variation was not associated with the net flow of livers. Also, although listing rates represent current demand for liver transplantation, the mechanism of this varying demand remains unclear; it might represent a variation in medical need for transplantation or a variation in the referral and listing practices. We were able to include only 9 months of import and export data for the recently implemented Share 35 policy.

Increasing organ donation is an important goal for everyone in the transplant community, and as long as there is any room for improvement in OPO performance at generating donations, then such improvement must be pursued. The liver allocation system does create a flow of organs among OPOs, but not from better performing OPOs to poorer performing OPOs, as has been hypothesized. Rather, organs flow from lower demand OPOs to higher demand OPOs, where demand is measured by incident listings at MELD scores ≥ 15. Studies that could resolve whether these highly disparate listing rates reflect disparate access to listing or real differences in liver disease burden would be a major contribution to our understanding.

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